

# Remarkable events and EAS properties in the knee energy region up to the LHC energy range

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After extensive simulations of  $\gamma$  ray families with CORSIKA in the energy region  $3 \times 10^{15}$ - $10^{17}$  eV, we have obtained from the fluctuations generated by standard  $Lns$  collider physics alignments of secondaries in the stratosphere and at ground level. The remarkable event registered on the Concorde doesn't fit well however those cases of artificial coplanar emission ; The possible hints of new mechanisms, especially the valence diquark breaking, are considered in the perspective of associated consequences visible in the EAS development.

## 1. Introduction

One event exhibiting aligned secondaries presented in the analysis of the earliest emulsion chamber experiment of Chacaltaya [1] and the the double core structure observed in binocular families up to a total energy of 1500 TeV could be the preliminary form of coplanar emission [2] . After those possible precursors, the attention was motivated by the events recorded in Pamir X ray chamber[3] , in Kambala, in Kascade, but also in balloon experiments (RUNJOB) and in the low stratosphere with high resolution X ray emulsion chambers in the Concorde[4] ; in this last situation, the geometrical criteria used to select an alignment treat directly the coordinates of the individual  $\gamma$ 's, either the linear coefficient[5]:

$$r = \frac{\sum_i^n (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i^n (x_i - \bar{x})^2} \sqrt{\sum_i^n (y_i - \bar{y})^2}} \quad (1)$$

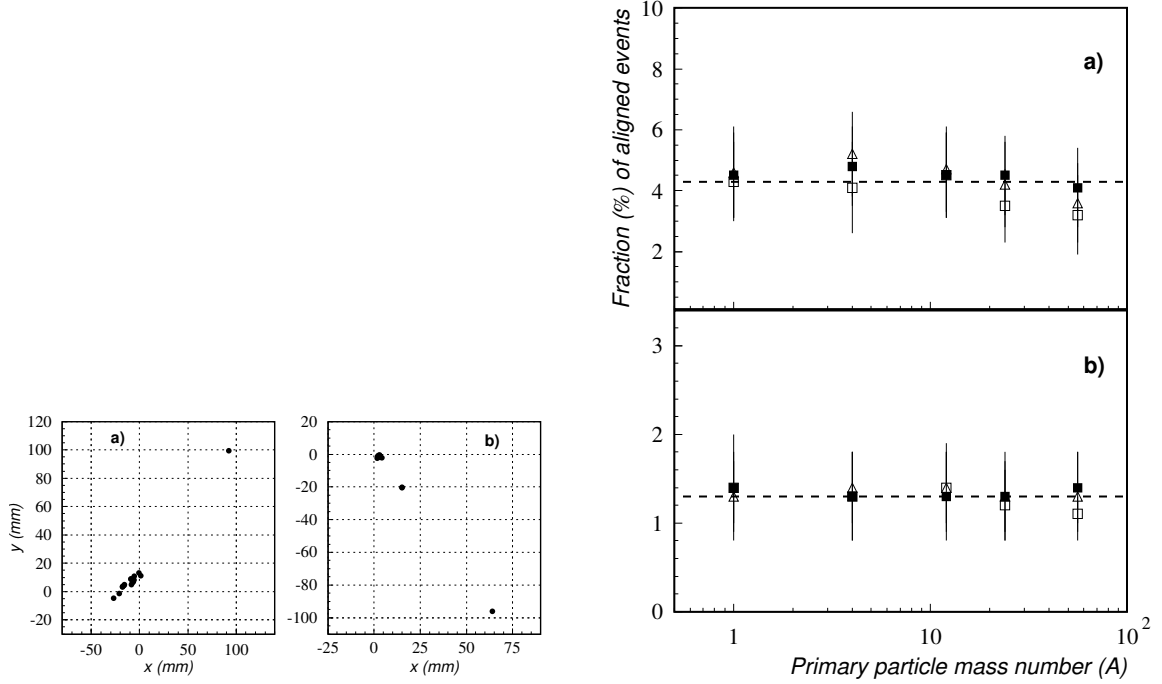
or the parameter  $\lambda_n$  introduced by Pamir Collaboration [3] and defined as:

$$\lambda_n = \frac{\sum_{i \neq j \neq k}^n \cos 2\varphi_{ij}^k}{n(n-1)(n-2)} \quad (2)$$

where  $\varphi_{ij}^k$  is the angle between the straight lines joining the  $i^{\text{th}}$  and  $j^{\text{th}}$  particles to the  $k^{\text{th}}$  one ( $0 \leq \varphi_{ij}^k \leq \pi$ ).

Both approaches help to select straight structures when their absolute values are close to 1 and have comparable advantages for this specific planarity [5] In our simulation, the primary particle is assumed to be in turn a proton, an  $\alpha$ -particle ( ${}^4_2\text{He}$ ), a carbon ( ${}^{12}_6\text{C}$ ) nucleus, a magnesium ( ${}^{24}_{12}\text{Mg}$ ) nucleus and in the end an iron ( ${}^{56}_{26}\text{Fe}$ ) nucleus. The zenith angle is chosen at random in the range  $0-30^\circ$ . The asymmetry parameter  $\lambda_n$  is calculated for the 4 and 5 most energetic secondary hadronic clusters. Alignments have been easily obtained (Figure 1), independently on the models (as far as they have similar transverse momenta distribution), and practically on the primary mass and on the primary energy [6]. As shown on the Figure 2, for the Pamir experiment, the three models involved give values very close to each other and, within the error bars, independent of the primary particle type. They are equal on average to  $(4.3 \pm 1.4)\%$  for the aligned events with  $\lambda_4 \geq 0.8$  and  $(1.3 \pm 0.4)\%$  for  $\lambda_5 \geq 0.8$ .

From our set of simulations, we show as an other example the dependence on the primary energy at balloon altitude (Figure 3).



**Figure 1.** Left: Examples of a pair of simulated events similar to JF2af2 with 23 (a) and 18 (b) aligned  $\gamma$ -rays ( $\gamma+e^\pm$ ) above 10 TeV. Right: Calculated fractions (%) of the aligned events with  $\lambda_4 \geq 0.8$  (a) and  $\lambda_5 \geq 0.8$  (b) for the Pamir experimental condition obtained by different hadronic interaction models: HDPM (opentriangle), QGSJET (fullsquare) and SYBILL (opensquare). The dashed line represents in both cases the average value.

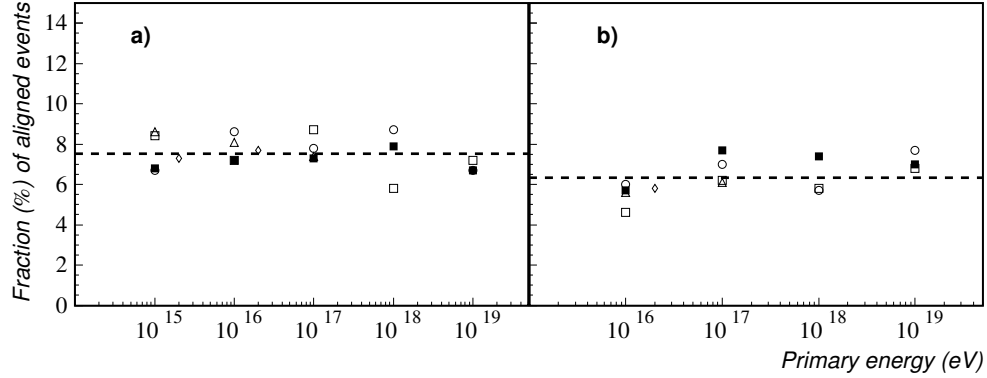
## 2. The Concorde event near $10^{16}$ eV

Tracing back the events produced with CORSIKA (Figure 1), we have observed that an unbalanced  $p_t$  received in the first collision on an energetic  $\pi^0$  could produce an alignment when the cascade starts 10km above the chamber.

	DPMJET	HDPM	QGSJET	SIBYLL	VENUS
$ r  \geq 0.94$	0.7	1.5	0.6	0.5	0.9
$\lambda_4 \geq 0.8$	7.4	8.0	7.4	7.4	7.1

**Table 1.** Calculated fractions (%) of the aligned events with at least 4  $\gamma$ -rays ( $\gamma+e^\pm$ ) above 10 TeV for with  $|r| \geq 0.94$  (first row) and  $\lambda_4 \geq 0.8$  (second row) for different high energy hadronic interaction models.

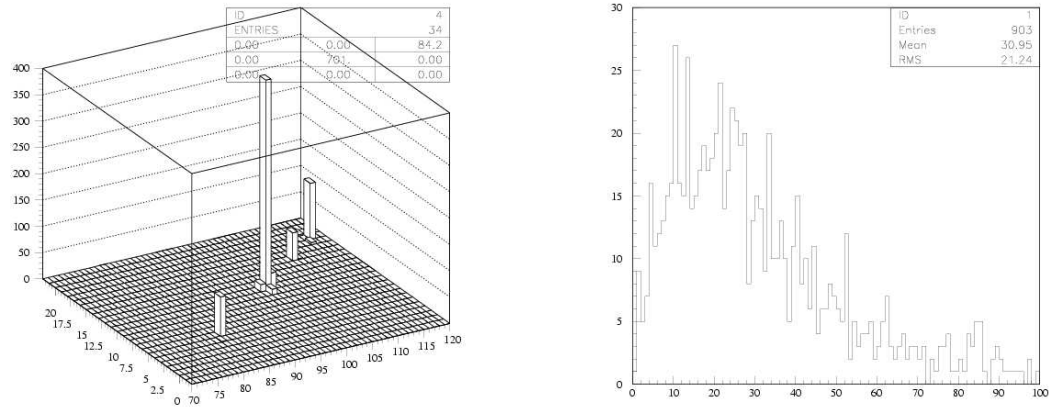
The primary cosmic ray particle in Table 1 is assumed to be a proton of  $10^7$  GeV, the observation level is identical to the Concorde flight altitude (17 km) and the zenith angle is selected at random in the range 0–70°. The number of simulated showers in each case is equal to  $10^4$ ; the results from the different hadronic models are on the whole consistent with one another. Among the 211  $\gamma$ 's of the JF2aF2 Concorde event, we



**Figure 2.** Calculated fractions (%) of the aligned events with  $\lambda_4 \geq 0.8$  for a primary proton (a) and a primary iron nucleus (b) as a function of the primary energy obtained by different hadronic interaction models: DPMJET (opencircle), HDPM (opentriangle), QGSJET (fillsquare), SYBILL (opensquare) and VENUS (opendiamond). The dashed line represents in both cases the average value.

show on a lego plot the energy deposited in a plane perpendicular to the axis by 34  $\gamma$ 's (about one half of the total energy deposited, i.e. 1600 TeV). Inside, the alignment, the four most energetic  $\gamma$ 's with respective energies, 300 TeV, 105 TeV, 75 TeV and 53 TeV are lying on a perfect straight line [5] with  $r = 0.9993$ . The invariant mass histograms for the different clusters (Fig.5) suggest an interaction level at about 100m above the Concorde, in contradiction with the simulation on the basis of standard physics requiring about 10km. We have verified on a small sample of simulated events that, in spite of a few secondaries of 2nd or 3rd generation (via bremsstrahlung or pair production) that those histograms, from the position of their maximum, return correctly the the origin of the collisions (at least in the stratosphere). Taking the 3 most important clusters (87% of the energy, 70% of the number of  $\gamma$ 's) as well as the whole event[4], we obtain a distance of the vertex to the chamber of 80 – 100m, instead of a distance in the range of 10km. Such circumstance suggests a violent phenomena separating the valence quarks of the proton projectile, especially the valence diquark, which cannot be recombined with a quark of the sea, suppressing the leading baryon at the end of the collision.

One hypothesis is that the original rotating relativistic string between the valence quark and the valence diquark becomes a more complex system with a secondary string (centered on the barycenter of the diquark) between the two quarks partners of the diquark. The maximal tension of the strings occurs when the quarks are at the largest distance from each other, i.e. when the 3 partons are on a common diameter which would be the axis of the fragmentation. The shorter mean free path of the diquark in the target nuclei could help the phenomena. As a consequence of the suppression of the leading particle,  $T_{max}$  is expected to level off during one decade after the maximum[7] and some typical behavior would have to be observed in EAS (changes of slope in muon electron dependence, flattening in the age parameter versus size, different absorption length, enhanced steepness of the most energetic  $\gamma$ 's and hadrons spectra). From other part, there have been few simulations with primary nuclei, and the recent proposition of a predominant  $\alpha$  component suggests to examine more carefully the asymmetries in light nuclei collision which explain the coplanar emission, for instance effects like the giant dipole resonance observed at very low energy, separating on each side of the nucleus the protons and the neutrons.



**Figure 3.** Left: Lego plot of the energy deposited by 34  $\gamma$ 's in the alignment (energy in TeV on vertical axis, x, y in mm) Right: An example of the histogram of invariant mass for cluster A, with the mass of the  $\pi^0$ , the maximum gives an interaction distance near 100m

### 3. Conclusions

A large proportion of the alignments may be explained by fluctuations. However, the alignments observed in the stratosphere indicate the necessity of a more careful analysis and the collection of new events, in the low stratosphere. 5000 Hours could be available for a scientific payload during the certification of the Airbus A380. The flights carried at an altitude of 13.1 km ( $170g - cm^{-2}$ ) with 10 emulsion chambers, similar to those used in Concorde, would multiply by 100 the statistics of remarkable  $\gamma$  ray families. This remains the most simple approach to the behavior of the valence quarks, at energies close of the LHC energy range.

### References

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